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ON

BOILER INCRUSTATION

AND

CORROSION.

BY

F J. ROWAN.

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PREFACE.

THERE is perhaps no subject connected with Engineering Science which at the present time commands more attention or causes more perplexity than does the compound subject of this paper. In Marine Engine practice its difficulties are most keenly felt; and of itself that is a field of operation large enough, as it involves interests sufficiently extensive, to give great importance to the subject, and to demand the utmost exertions of engineers towards the solution of its problems, and the providing of remedies or preventive measures against the ravages of what is an active and powerful agent in the destruction of their works. But the range of action which this destructive agent has is bounded only by that which puts a limit to the use of steam, and hence many other interests besides those of engineers are involved in the matter.

The state of general information about this subject is very unsatisfactory, because it amounts only to the fact that obscurity, or at least uncertainty, prevails. Yet many facts of the greatest interest and importance have been observed and noted, and, as is usual in such cases, there are some men who have considered these in the light of their own experience with the intelligence which is needed in order to turn all to good account. As the subject is partly a chemical and partly a mechanical one, it demands, in order that it may be successfully grappled with, a combination of scientific and practical information which, in consequence of defective educational methods, has not frequently been found among engineers.

I propose to myself in this paper the simple task of bringing together these scattered facts and observations, adding to them in whatever measure I am able, in order to elucidate if possible the full truth of the matter. The course of investigation and inquiry which have been called forth has been marked by the suggestion of various remedies. The earlier stages have produced the recommendation of a variety of empyrical remedies or nostrums—substances which have been proposed apparently for every conceivable reason except an intelligent perception of the nature of the action to be counteracted, and consequently of the qualities requisite in the remedy. A list of these applying to Incrustation is given in a paper by Mr. Jas Napier, published in the *Proc. of the Phil. Soc. of Glasgow* (vol. iv., 1855-58), who gives also some account of the more rational methods proposed in his day. For Corrosion a similar list has in recent times appeared—too large, however, to quote at length; and some methods of working have been proposed which have been more or less successful under special circumstances, but all partial in their application. Of these comes the endeavor to form a scale of salt by the use of a proportion of sea water, the use of zinc in the boilers, filtering the feed water, &c.

There seems to be in some quarters the idea that Incrustation and Corrosion of Boilers, inasmuch as in general they both result in the destruction of the boilers, are one and the same action. But although this is an error, and the two actions are very dissimilar, yet they are so often united in effecting the destruction of boilers (and almost all crusts contain iron), and are so often present successively in the same boiler (*i.e.*, a crust being formed and then decomposed or partially decomposed, with injury to the boiler), that an examination which did not include a notice of both could not lay claim to any degree of completeness.

ON BOILER INCRUSTATION AND CORROSION.

INCRUSTATION.

A FEW years ago the attention of all concerned was exclusively directed to Incrustation, its evils and prevention. The evils produced by it are numerous, for boilers when coated with crust quickly accumulate layers of this material, which is a bad conductor of heat, and thus are not only hard to steam, requiring a large excess of coal, but are more quickly worn out and sometimes suddenly oxydized or "burned" in consequence of the increased temperature rendered necessary in the furnaces. Dr. J. G. Rogers, of Madison, United States, in a paper published some years ago, estimated the conducting power of crusts as compared with that of iron as 1 is to 37.5. A scale

1-16 inch thick, he says, requires an extra expenditure of fifteen per cent. more fuel, and this ratio increases as the scale is thicker. Thus, when it is ¼ inch, sixty per cent. more fuel is needed; ½ inch, 150 per cent., &c. The temperature of the heating surface of the boiler must be raised in proportion to the thickness of scale. Thus, while to produce steam of a pressure of 90 lbs., water must be heated to about 320° Fah., and this can be done in a clean boiler with ¼-inch plates by heating the boiler surface to about 325°; if ½-inch of scale intervenes between the shell and the water, it will be necessary to raise the temperature of the heating surface to about 700°—almost low red heat. Iron oxydizes the more rapidly the higher the temperature at which it is kept, and at any heat above 600° it very soon becomes granular and brittle, and is liable to give way under pressure. This condition predisposes the boiler to explosion, and makes expensive repairs necessary, and the presence of scale also renders the raising and lowering of steam slower.

The proper circulation of the water is also interfered with by the presence of crust. Both economy and durability thus require the absence or prevention of crust.

There are two distinct classes of boilers which are subject to incrustation, and these are:

(1) Land boilers using natural fresh waters, and
(2) marine boilers using sea water.

(1) There is no doubt that the quality of natural fresh waters varies between wide limits, from rain water on the one hand, which contains no mineral impurities, to that of highly-charged mineral and chalybeate springs on the other.

An examination of the analyses of waters supplied to the principal manufacturing towns in Britain (such as, for instance, are published in the Report of the Registrar-General), and comparison with that of rivers in other countries, demonstrate that no better general or average illustration of this class can be met with than is afforded by the River Clyde water, which was in general use in Glasgow and neighborhood prior to the introduction of Loch Katrine water, and which is still used in some manufacturing establishments. As analyzed by Dr. Wallace in 1848, that water contained the following impurities, which are here tabulated in grains to the gallon :

Clyde Water as Supplied to Glasgow in 1848.

Carbonate of lime	2.52
Carbonate of magnesia	.72
Sulphate of lime	26
Sulphates of potash and soda	1.94
Chloride of magnesium	.40
Chloride of sodium	.54
Oxyde of iron	trace.
Phosphate of lime and alumina	.31
Silica	.28
Organic matter	.89
Total	7.86

Dr. Wallace (to whose courtesy I am indebted for the above and other information on this subject, and for much valuable assistance in connection with this paper) has informed me that the total amount of solid matter in solution in this water increased in quantity gradually, and that in 1854 it amounted to ten or eleven grains per gallon.

The incrustation formed upon ordinary steam-boilers, working in mills at from 15 to 20 lbs. per square inch pressure of steam (above the atmosphere) and using that water, analyzed by the same authority, is found to consist of :

	Per Cent.
Carbonate of lime	66.00
Magnesia	6.05
Sulphate of lime	4.28
Water, with traces of carbonic acid	8.72
Oxyde of iron, alumina, and phosphate of lime	5.85
Silica	8.10
Organic matter	1.00
	100.00

This crust, which is of a dark brown color, and is hard, forms rapidly on the interior of the boilers, and is difficult to remove. But it has been found that by a moderate use of soda-ash this formation is readily stopped or held in check.

The quantity of soda ash used in a pair of boilers (one 30 horse-power, 6 feet 6 inches diameter by 21 feet long; one 40 horse-power, 7 feet 6 inches diameter by 27 feet long) at the works of Messrs. P. Bogle & Co., at Barrowfield, which together require about 9,700 gallons of water per week, is six lbs. per week in both boilers. This is dissolved in water, and fed into the two boilers once a week.

The action of this soda-ash or carbonate of soda, under these circumstances, is a very interesting one, though perhaps not well understood by those using the substance in this way. Sulphate of lime is decomposed by its means and precipitated as carbonate, while a soluble sulphate of soda is formed. The neutral carbonate of lime is likewise produced by reaction from the bicarbonate in solution, and, as thus formed, it will not adhere to the boiler surfaces, but separates as a loose powder or mud, which can be blown out of the boilers or otherwise removed as sludge. In those boilers under notice the quantity of this sludge is found to be three pails full from each boiler every three months.

It has been found, however, that where the neutral carbonate of lime is produced slowly by the action of heat—which drives off part of the carbonic acid from the bicarbonate existing either in solution in the water or as a solid already deposited upon the boiler surfaces—that in this case the neutral carbonate possesses the property of being able to adhere firmly of itself to the boiler plates. It seems to be in this case partially crystalline. Thus the special advantage arising from the employment of soda ash is that it decomposes the bicarbonate rapidly, probably because of the presence of some soda uncombined in the ash, and that the neutral carbonate is precipitated as a loose powder, which will not adhere unless fused or agglomerated by means of some other substance.

Concerning this latter point, M. Bidard, of Rouen, has informed me that his numerous examinations of boiler incrustations have demonstrated the fact that the presence of organic matter is necessary for the formation of boiler crusts which consist essentially of carbonate of lime. Such crusts he has produced artificially, in order to verify his theory. Fresenius, however, quoted by Dr. Wallace, without specially noticing the presence of organic matter, has attributed a cementing property to sulphate of lime, which he always found present in boiler crusts. M. Bidard's explanation thus applies specifically to those crusts which contain carbonate of lime and no sulphate, for it is probable that where sulphate is present it possesses agglomerating power of itself sufficient to render the presence of organic matter unimportant in these instances. This is demonstrated in examples, in some marine boilers for instance, where crusts are formed without organic matter being present in appreciable quantity, of which the analyses by Dr. Wallace are specimens.

But M. Bidard's remarks show that soda ash might be used with muddy water, such as canal water for instance, and yet a hard incrustation would form. In such a case there would be no preventive but the use of a filter for all the water passing into the boiler in addition to the use of soda ash there.

The use of too much soda ash is injurious in its effects, as the excess boils up and passes over in the steam to cylinders and pumps, where it clogs the pistons and otherwise interferes with proper working by making combinations with the oils and greasy matters employed in the machinery. The lavish use of oils and grease of course intensifies this action where it is present, and it has been found that the carbonate of lime itself has passed over from the boiler with the steam, and has entered into combination with the grease where enough was to be found.

All that is needed, however, in working with soda ash is a little intelligent care, and as the matter is simple, a system of working is soon arrived at. As an example, I take the boilers already mentioned of Messrs. Bogle & Co., at Barrowfield. Under ordinary circumstances the manager, Mr. Keith, proceeds, as I have said, blowing out the boilers once in three months. When, however, there is a fresh or "spate" in the river the quantity of inorganic solids in the water is proportionately less, and the quantity of soda ash introduced is in consequence diminished. Muddiness in the water seen in the gauge glasses is a sure test if too much is being used, and when this is noticed and acted upon no inconvenience from material passing over to the cylinders is found to result.

An interesting fact may be mentioned in connection with this part of the subject, and as illustrating how calcareous waters sometimes contain soluble matters which themselves counteract their crust-forming ingredients. The boilers of Messrs. G. & A. Harvey's engineering works in McNeill Street, use the water drawn from the Clyde at a point which is considerably below Barrowfield, the water being contaminated by the refuse from print works and other factories, discharged into it between the two points.

A comparative estimation, by Dr. Wallace, of the qualities of the water from both localities is here tabulated:

	I. From Barrowfield.	II. From McNeill Street.
Total solids per gallon..........	8.96	15.12
Insoluble in water, carbonates of lime and magnesia, silica, &c..	2.94	3.78
Soluble salts	3.92	6.72
Organic matter, &c. (loss by ignition).......................	2.10	4.62
Alkalinity expressed in soda.....	.014	.056

The marked difference in amount of total solids per gallon, and in the amount of soluble salts and degree of alkalinity, shows that a decided change has been effected in the water by the time it reaches McNeill Street. In using it in the boilers there, it is only after a considerable time, and in corners of the boiler that a crust is formed. The ingredients of the water seem in general to re-act naturally, and in regular working only a deposit of loose mud collects, which is blown out of the boilers each morning.

The composition of the crust, as analyzed by Dr. Wallace, is given below, but a full analysis of the water would be required in order to show what re-actions take place in working:

Carbonate of lime	64.98
Sulphate of lime	9.33
Magnesia	6.93
Combined water	3.15
Chloride of sodium	.23
Oxide of iron	1.36
Phosphate of lime and alumina.	3.72
Silica	6.60
Organic matter	1.60
Moisture at 212° F	2.10
	100.00

The use of soda-ash as a preventive of the formation of incrustations in boilers working with calcareous waters is so rational and simple that it has, from a comparatively early date, commended itself to chemists, and has been, by them, repeatedly proposed to engineers. The material itself possesses for the majority of cases, where such is called for, all that it is requisite an anti-incrustator should possess, while, if used with average care and intelligence, it is not capable of acting destructively. Its application is simple, as it may be added in solution either periodically—as in the case of the boilers quoted, or, better, regularly and steadily in fixed proportion to the quantity of water fed into the boiler, after the manner proposed by Mr. James Napier in the paper already alluded to. There is also no reason why it should not be added in proper proportion to the water in the feed tank or cistern, instead of being put into the boiler. In this way, as the re-action between soda ash and sulphate of lime does not require a high temperature or pressure, the precipitated carbonate of lime could be arrested, and comparatively pure water fed into the boilers, frequent blowing-off being also rendered unnecessary.

With waters containing only a little sulphate, and chiefly carbonate of lime, it would be necessary, however, to introduce the soda salt into the boiler, as a temperature of 100° Cent. (212° Fah.) is requisite for the decomposition of the bicarbonate of lime.

A short examination of the various remedies against incrustation which have been proposed, will not be uninteresting, although it results in the conviction that most of them are unsatisfactory.

Oxalate of soda and tannate of soda were proposed by Dr. Rogers in America, in order to form, by decomposition of the lime salts, insoluble oxalates and tannates; but these would seem to increase the amount of solid matter precipitated, and, although proposed some years ago, to have been little used.

Lime and zinc have been used with some degree of success, but their action is confined to combining with the carbonic acid of the bicarbonate of lime. On sulphate of lime they have no action.

The object in view in the proposed use of starchy and gelatinous matters has been to prevent scale forming, by enveloping the precipitated or crystallized solids with gelatinous covering, and so to delay their settling by diminishing their weight. But M. Bidard's observations on the effects of the presence of organic matters (especially in so-called "anti-incrustators," or compounds for preventing incrustation) at once sweeps the field of all remedies of an organic composition, proving them to be injurious by doing the very thing which they are supposed to prevent.

Still, however useful as a precaution where the admission of extraneous organic matter can be prevented, this as a system of preventing incrustations manifestly fails where the water contains organic matter in solution.

Sal-ammonia, proposed by Ritterbrandt, and hydrochloric acid, are both open to the objections that their preventive action is only partial, and that they have the power of seriously injuring the boilers and connections.

Crude pyroligneous acid has been suggested for action upon carbonates alone, while Petroleum has been extensively used in the United States with a measure of success, not only in preventing incrustations, but also in removing those already formed. Its action has not as yet been investigated, as far as I am aware, but it is probable that its effects are due to decomposition of hydrocarbons. This seems to be borne out by a report by the Chief Engineer to the Steam Boiler and Inspection Co. of Hartford, U. S., who states that "petroleum works better where sulphate of lime predominates than in waters impregnated with carbonate of lime. We would not," he says, "advise it in connection with this latter." This simple fact renders it useless in the majority of boilers using fresh water in this country.

Soap acts upon both carbonate and sulphate of lime, but the quantity appears to be increased by the formation of lime soap, and thus the boiler is made filthy; a corrosive crust is sometimes formed, and priming and other evils also result from its use.

Recently a substance called "Burfitt's Composition" has been patented for the prevention of boiler incrustation, but it has been found to consist essentially of organic matters, and moreover has rather increased than prevented incrustation where it has been used.

Two other methods of prevention have also been devised, and seem to be founded upon the fact which Professor Mills imforms me was first observed by J. Y. Buchanan, that barium chloride decomposes sulphates and liberates the carbonic acid in water.

One of these, called "De-Haen's process," which consists in the use of barium chloride and milk of lime, is now extensively used in Austria and in Krupp's Works in Prussia. A recently published statement of the comparative cost of working on this system, and with water containing gypsum, without an added re-agent, shows that to purify 33 cubic meters of water when containing five parts gypsum in 100,000, the cost is 6d., and when containing thirty parts gypsum the cost is 3s. Practical working with this process for twelve months with one or two boilers (it does not appear very clearly whether one or two), showed an increase of expenditure amounting to 500 florins, against which was to be placed the saving in fuel resulting from absence of incrustation, and reduced repairs from the same cause, the value of these, however, not being stated.

The analysis of deposits which have been found to accumulate in the steam pipes, &c., where these processes have been used, impress us with the idea that these methods are, however, open to some serious objections in practical working on account of the formation of salts of barium.

There is, however, one system of working which has yet to stand its trial, but which it is perhaps not extravagant to consider as inseparably connected with the advancement of engineering science and appliances upon which alone it depends. That is the working of land boilers in connection with surface condensers, and so supplying them with pure water. No incrustation is possible with this method, and its theoretical advantages in point of economy seem to justify the belief that its present limited adoption will prove merely the precursor to its more general introduction. It becomes of all the more importance in view of the extended use of sectional or water tube boilers, because with these, on account of small water spaces, no mere preventive measures against the formation of incrustation suffice. Solid matters ought to be excluded from all such boilers.

2. It is necessary, in connection with incrustation, to consider marine boilers working with sea-water, because although modern systems of marine engine practice with compound engines and surface condensers, wherever these have

been adopted, have banished incrustations; yet these systems have not yet been universally adopted, and there is even a disposition with some to return to the régime under which incrustation held sway. The evil effects of incrustation make themselves felt with multiplied force in marine boilers, because of the great rapidity with which the crusts form, in consequence of the large quantity of solids contained in the water. I am informed by Mr. Tookey, of the Royal School of Mines, that British Channel water contains 2467 grains, and North Sea water 2408 grains in the gallon; and it has been shown by Mr. James R. Napier, F. R. S., that sulphate of lime begins to deposit before one half of the water is evaporated.

In addition to this rapidity of formation of crust, the space at command for storage of fuel is limited. Large quantities of chemical re-agents cannot for a similar reason be carried; and because of the confined space in which boilers and men working at them are placed on board ship, the results of an accident to, or the destruction of, the boilers are serious; while great difficulty is also experienced in getting repairs effected in foreign ports generally. All these considerations render it of the greatest importance that marine boilers should be freed from incrustation. Besides these, there are reasons connected with the formation of sea water scale, which render its presence in boilers undesirable.

Considered from a chemical point of view, the problem of preventing incrustation in these boilers, appears to be similar to that experienced with land boilers, inasmuch as the substances composing the crusts are similar in both cases, although differing in their proportions in the formations. No doubt, as we have seen, soda ash is the best chemical preventive where that substance has to be used in ordinary circumstances, but the comparatively enormous quantity of solid matters present in sea-water causes the use of soda ash to be attended with so many inconveniences, and so much expense as to render it here practically useless. In these circumstances it has to be combined with blowing off from the boiler in order to get rid of the solids, it being necessary, as Mr. J. R. Napier showed, to blow off th of the feed water, and neutralize the sulphate of lime in $\frac{8}{10}$ths with soda. The loss of heat from this blowing off is considerable, and it is combined with the cost of the large quantity of soda required for neutralizing. Yet this process is not worse than the ordinary mechanical one of discharging the saturated, or what is supposed to be the saturated, water from the boilers which has been most generally restored to. In this case the indications of the salinometer are depended upon, and fully $\frac{5}{10}$ths of the feed water have to be discharged, little of its heat being utilized. With regard to this Mr. Jas. R. Napier has said of the example of a vessel whose boilers worked at a temperature of 270° that "a quantity of fuel equal to 15½ per cent. of that which produces evaporation is consumed by the ordinary blowing-off method in order to prevent crust, and this amount increases with the temperature."

The salinometer might prove, and perhaps has often proved, a fallacious test, for if it were applied after a large quantity of the solids had been precipitated from the water, it would deceive the engineer by showing a less density than had existed previously, and thus mislead him as to the state of the boilers and of the water. In result it has been always necessary to chip and hammer away scale from the interior of marine boilers worked with sea water to an extent not advantageous to them.

Undoubtedly the most sensible and efficacious method of preventing incrustation in these boilers is to work with fresh water. This has been rendered possible in many instances by the introduction of the Surface Condenser into practical working, and no doubt the desire to avoid the evils of Incrustation has operated in bringing about the introduction of that system which is at present the most general in marine engineering. On the other hand, however, the commencement of this era in engineering practice has been the introduction of engineers to all the evils and difficulties of Corrosion.

Before dismissing the subject of Incrustation, I wish to direct attention to the following analyses and notices of the decompositions which take place in sea water in boilers during the formation of crusts, as these throw considerable light on the subject of Corrosion. The following analysis of Black Sea water was given me by the late Prof. Penny. I quote it only as showing the various ingredients contained in sea water, as I have no means of ascertaining its accuracy now—

Black Sea water, sp. gra.	1.01365
Chloride of Sodium	14.02
Chloride of Potassium	.19
Chloride of Magnesium	1.310
Bromide of Magnesium	.005
Sulphate of Lime	.105
Sulphate of Magnesia	1.470

Carbonate of Lime	.365
Carbonate of Magnesia	.209
Total salts in parts per 1000	17.674

The following analyses were made by Dr. Wallace, Nos. 1, 2, 4 and 5, for a paper of his on Boiler Incrustation, published some years ago; the others kindly undertaken for me along with other investigations inserted in this paper.

No. 6 differs from the rest in being merely a deposit. I have arranged them in tabular form, in order to show as far as posssible their relation to one another as having been formed at different pressures of steam—

ANALYSES OF BOILER CRUSTS AND DEPOSITS.

	No. 1.	No. 2.	No. 3.	No. 4	No. 5.	No. 6	No. 7.
Sulphate of Lime............	33.95	66.88	69.77	74.21	72.85	57.34	76.83
Magnesia....................	40.05	18.96	15.75	14.95	13.18	1.94	1.81
Carbonate of Lime...........	—	—	3.44	—	.34	—	—
Common Salt................	traces	traces	.99	2.04	2.16	1.72	2.24
Phosphate of Lime, Alumina,	1.33	.50	1.14	1.34	2.40	—	—
and Oxide of Iron........	—	—	.22	—	—	27.04	13.76
Silica.....	traces	traces	.16	.57	.80	7.60	2.24
Water with traces of Carbonic Acid..............	24.67	11.66	8.25	6.89	8.27	4.30	3.78
Total......	100.00	100.00	99.72	100.00	100.00	99.94	100.66

No. 1 is from the Cunard steamer Asia, probably worked at about four or five lbs. per square inch pressure of steam.

No. 2 is from the King Orry, worked at about five to ten lbs. pressure.

No. 3 is from the Propontis, worked at about ten lbs. pressure. Old boilers.

No. 4 is from the Cosmopolitan, worked at about ten to fifteen lbs. pressure.

No. 5 is from a Source unknown, worked at about (?) fifteen to twenty lbs. pressure.

No. 6 is from the Propontis, worked at about 150 lbs. pressure. Deposit before sea water was fed into Boilers.

No. 7 is from the Propontis, worked at about 150 lbs. pressure. Crust after sea water was fed into Boilers.

Dr. Wallace, in his paper quoted above, remarks: "These crusts differ from the insoluble matter obtained by simply evaporating sea water in open vessels, for that contains nearly four times as much carbonate of lime as carbonate of magnesia, while the crusts contain a large quantity of magnesia, and little or no carbonate of lime. The decomposition of soluble magnesian salts by carbonate of lime under the influence of a liquid boiling at a high temperature (say 270°) is exceedingly interesting. Sulphate of magnesia and carbonate of lime boiled with water under ordinary circumstances, do not re-act upon each other the in slightest degree; but it is evident that the result is brought about under pressure. The re-action with oxide of manganese, which is isomorphous with magnesia, is exactly similar, and is taken advantage of in the recovery of the manganese used in the preparation of chlorine, as practiced at the St. Rollox Chemical Works.

"Again, the condition in which the magnesia occurs is peculiar. We should expect a basic carbonate, but I find little more than a trace of carbonic acid in any of the crusts. (In No. 1 it was .28.) The magnesia exists essentially as the hydrate. The sulphate of lime appears to occur as the hydrate described by the late Professor Johnson, as having been found by him in a distinctly crystallized condition in a high-pressure steam boiler, its composition being represented by the formula $2(CaOSO_3) + HO$."*

Recently these results have been verified by the independent investigations of Dr. Ferd. Fischer who has proved from a number of analyses that various decompositions of the salts contained in waters take place under the influence of elevated temperature and pressure. Fischer quotes various authorities to show that gypsum gives off nearly half its water of crystallization at temperatures up to 100° (C.), and further proportions at higher temperatures, so that

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* Under the head Di-hydrated Sulphate of Lime, Gemelin says: This compound was deposited from the water in a boiler which was working under a pressure of two atmospheres; it formed a grayish granular mass of specific gravity, 2.757 appearing under the microscope in the form of small transparent prisms colored with carbonaceous matter.

		Calculation.	Johnson.
$2\ Ca\ O,SO^3$	136.	93.79	93.272
HO	9.	6.21	6.435
Carbonic matter	—	—	0.293
Totals	145	100.00	100.00

its solubility is considerably diminished. Above 140° it becomes totally insoluble in sea water, and at a lower temperature in fresh water, and hence is deposited as an anhydride. It is more easily soluble in water containing sodium or magnesium chloride in solution than in pure water. The effect of pressure on its solubility and that of other salts is shown by the following table of analyses of water from boilers :

(*See Table on opposite page.*)

He shows that only a portion of the calcium sulphate in boiler incrustations contains water of crystallization. In boilers which have been submitted to a very high pressure it occurs anhydrous. Magnesia exists as hydrate, the magnesium chloride giving up its hydrochloric acid under the influence of heat. The magnesium carbonate is decomposed at a temperature little above 100°, and magnesium sulphate undergoes mutual decomposition with calcium carbonate, the carbonic acid escaping. From a number

One liter of Water contains—	At 3 atmos.	At 1.5 atmos.	Taken with mud when blowing off Boiler.
$Ca\ So_4$ ($Ca\ O,SO_3$)… …….	0.885 gram.	1.136 gram.	3.028 gram.
$Ca\ Cl_2$ ($Ca\ Cl$)……………	1.008 "	—	—
$Mg\ Cl_2$ ($Mg\ Cl.$)………….	3.479 "	0.189 "	0.769 "
$Na_2\ SO_4$ ($Na\ O,SO_3$)……..	—	0.104 "	5.161 "
$Na\ Cl$………………….	4.743 "	0.478 "	9.582 "
Residue found on Evaporation	7.210 "	—	18.864 "

of analyses given it is noticeable that the higher the pressure, and consequently the higher the temperature, up to 3 atmos., the larger the quantity of $2CaSO_4 + H_2O$, in comparison with the $CaCO_3$. But, contrary to the opinions of many, Fischer holds that carbonate of lime suffices of itself, or probably also aided by silica, to form a hard crust.

It appears from analyses of marine crusts to be probable also that the quantity of Na Cl in the crusts increases with increase of the steam pressure under which these have been formed.

CORROSION.

From one or two causes, corrosion has been found to attack the exterior surfaces of boilers, and eventually to work considerable damage. This, however, is a simple matter, as the action in these cases is easily preventible.

Thus, in the case of land boilers, careless setting in too much lime, has produced bad effects—the part of the boiler shell exposed to the, probably impure, lime having been eaten away to a large extent.

Setting the boilers upon a damp foundation without proper provision for draining, has also resulted in rapid destruction, whether the moisture reached the boilers through the lime of the setting or through the ashes.

Both marine and land boilers have been seriously corroded by ashes when cold having been carelessly allowed to remain in contact with the iron. The ashes contain a considerable quantity of alkaline salts of some strength, and with damp drawn from the bilge water in vessels, or from the ground ashore, or by deliquescence from the atmosphere, these salts have been enabled to attack the iron vigorously.

It has also been found by S. Dana Hayes (*Chem. News*, vol. xxx., 153, *Jour. Chem. Soc.*, vol. xiii., p. 294), that the soot in tubes and flues has become charged with pyroligneous acid, where wood has been freely used in lighting fires, or large quantities of coal have been charged at a time; and that this combination has caused corrosion. The same result has been caused by the soot retaining fine dust of ashes, and in consequence also sulphur acids, derived from pyrites in the coal. A case of this kind is also published by J. W. Chalmers Harvey, in *Chem. News*, xxxii., 252, *Chem. Soc. Jour.*, No. clxi., p. 796.

It is sufficient, however, to point out

these causes, for they suggest their own remedies. Care in preparing and completing the setting, in cleaning flues and ash pits, and in firing being all that is necessary to prevent corrosion from them.

The injudicious use of brass cocks and connections bolted or fastened directly to the boiler shell, has often resulted in corrosion from galvanic action at the places where the two metals come in contact. This action proceeds more rapidly when a little leakage of water takes place at the joint or connection.

The operation of corroding forces in the interior of boilers, is, however, far more serious and baffling. Yet even these forces may be reduced to submission, but they demand study in the becoming spirit of patient enquiry.

Many investigations of these forces and their actions have been made, and it is advisable to review these before attempting to deal with the subject from an engineering point.

One of the first to publish experiments

and trials connected with the corrosion of metals was the late Prof. Crace Calvert, who exposed iron and steel (with other metals) to the action of sea-water, of natural fresh water, and of distilled water, with and without air. He also submitted iron and steel to the action of various gases, with and without moisture, and to that of various acids. In general the results obtained by him showed that steel and then iron were most rapidly corroded by sea water when simply immersed in the sea for a time. (105.31 grammes of steel and 99.30 of iron being dissolved from plates of forty centimeters square by immersion in the sea for one month.) Also that iron immersed in water containing carbonic acid oxidised rapidly with escape of hydrogen gas, which led him to suppose that some galvanic action had part in the operation. He may, however, have meant merely thus to designate the decomposition of a part of the water by which oxygen was dissociated and combined with the iron under the influence of the carbonic acid. The corrosive action of carbonic acid was corroborated by his experiments with gases, for when bright blades of steel and iron had been exposed for four months to the action of various gases he obtained the following results: There was no oxidation with dry oxygen: with damp oxygen, one blade only out of three experiments was slightly oxidised: no oxidation with dry carbonic acid; with damp carbonic acid there was a formation of white carbonate of iron on the blades; no oxidation with dry carbonic acid and oxygen, but very rapid oxidation with damp carbonic acid and oxygen. He also found that distilled water which did not contain air or gases was without corrosive action upon iron, a bright blade which was immersed in such water having become in some days merely here and there spotted with rust. It was found that at these spots where oxidation had taken place, there were impurities in the iron which had induced galvanic action, "just as a mere trace of zinc placed on one end of the blade would establish a voltaic current."

An analogous action of distilled water with and without air was observed in his experiments with lead—200 litres of distilled water without air having dissolved during eight weeks only 1.829 grammes from a surface of 1 sq. meter, while the same quantity of distilled water aërated dissolved in the same time 110.003 grammes.*

These investigations were made the basis of an enquiry by Mr. W. Kent, of the Stevens Institute of Technology, into the corrosion of iron in railway bridges in the U. S., and by their means he was enabled to arrive at a satisfactory demonstration of the causes of the action. His paper was published in the *Engineer*, in Aug., 1875.

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* Sir R. Christison has made investigations into the action of water on lead (*Chemical News*, vol. xxviii. 15), but seems in his conclusions not to have distinguished between distilled water and pure natural waters, merely comparing them with respect to *purity*. Yet the fact that he always found carbonate of lead formed by the action of the purest waters suggest that the action was due to the presence of gases in solution and not to the water itself.

Recently, some of Calvert's results have been verified by A. Wagner, who publishes (in *Dingler's Polyt. Jour.*, 218.70-79) an important paper on the Influence of Various Solutions on the Rusting of Iron. Distilled water free from air does not appear to have been tested, but with air freed chemically from all carbonic acid, a slight rusting was noticed, the water, however, soon becoming saturated with its proper quantity of iron. The action of carbonic acid (or carbon dioxide) observed by Calvert is also noted, and the fact noticed for the first time that the presence of chlorides of magnesium, ammonium, sodium, potassium, barium, and calcium in the water largely increases the production of rust, while this important fact also appears from his results, that the corrosive action of all these substances is considerably increased by the presence of air and carbonic acid in solution. Chloride of magnesium of all these salts is the most active agent when alone in corroding the iron, but combinations of chloride of magnesium and carbonate of lime, of chlorides of barium and calcium, and of chlorides of sodium and calcium have also considerable corrosive action.

This to some extent corresponds with the fact observed by Mr. John Gamgee, as a difficulty which he had to encounter in connection with the continuous freezing of water for his "Glaciarium," viz, that the brine solutions used as media of congelation act destructively upon the metallic surfaces of the pipes or channels through which they are conveyed. (*Engineering.* vol xxi., page 226.)

Wagner, however, has also noticed that while chloride of magnesium solution in the absence of air attacked iron at a temperattre of about 100° Cent., the chlorides of sodium, potassium, barium and calcium were without action under these circumstances. This author also notices the fact, the observance of which is ascribed to Mr. Young, of Kelly (in a paper read by Mr. James R. Napier before the Phil. Society of Glasgow, Dec. 16th, 1874), viz., that the presence of an alkali in water protects iron and prevents rusting. In consequence of the great importance of his results, I give two tables of figures (from the four contained in his paper) representing some of them :—

(*See Tables on following pages.*)

I quote here an important experiment made by him on the effect of chloride of magnesium on iron at boiling temperature.

Two grammes of neutral magnesic chloride were introduced into a strong tube in which weighed pieces of iron were placed; boiling distilled water was added, and the tube sealed up while steam was issuing. It was then kept at 100° Cent. (212° F.) for six weeks, and after cooling was opened. Gas was evolved on opening it; the iron was black and had lost 0.39 per cent. in weight, and the solution when filtered

No.	Solution.	Percentage of loss of weight in one week.	
		With air free from CO_2.	With air and CO_2.
1	Freshly distilled water	0.83	1.53
2	Containing Ba Cl_2 and Ca Cl_2	1.63	1.46
3	Containing Na Cl and KCl	1.20	2.03
4	Containing Mg Cl_2	1.40	1.85
5	Containing NH_4 Cl	1.29	2.16
6	Containing $K(OH)_2$	—	—
7	Containing Na CO_3	—	—
8	Containing sea water	1.26	1.02
9	Containing sea water, evaporated, and oil 5 drops	0.47	0.73

No.	Solutions.	Boiling in contact with air then and while cooling.					
		Percentage of loss of weight—					
		1 week	2 wks.	3 wks.	4 wks.	5 wks.	6 wks.
1	Distilled water....................	0.44	0.82	1.15	1.53	2.02	2.46
2	Flask half-filled with distilled water —*i.e.*, more air...............	1.01	1.62	2.75	3.68	4.53	5.18
3	Containing Ba Cl_2 and $CaCl_2$......	0.66	1.33	1.57	1.82	2.03	2.27
4	Containing Na Cl and KCl.........	0.84	1.47	2.15	2 57	3.04	3.41
5	Containing Mg Cl_2................	1.31	1.91	2.20	2.49	2.76	3.05
6	Containing Mg Cl_2 and excess of Ca CO_3.........................	0.89	1.54	2.08	2.46	2.97	3.27
7	Containing NH_4 Cl	1.15	1.86	2.56	3.16	3.66	4.16
8	Containing $K(OH)_2$	—	—	—	—	—	—
9	Containing Na CO_3	—	—	—	—	—	—
10	Sea water..........	0.43	0.65	0.70	0.75	0.97	1.24
11	Sea water and Ba Cl_2........... ...	0.15	0.46	0.69	0.92	1.08	1.23
12	Sea water and 10 drops oil.........	0.59	0.59	0.62	0.72	0.83	0.93

contained chloride of iron (ferrous chloride). (*Dingler's P. J.*, ccxviii. 70-79. *Chem. Soc. J.*, No. clx. p. 522.)

Still another valuable contribution to our knowledge of this subject comes to us from Germany, in the results of an examination of the effects of condensed water containing grease on boilers which were fed with it, by Stingl, an author who also proposed and successfully carried out a method for the purification of that water.

The water was evidently condensed by means of an injection condenser, as salts of lime and magnesia were present in small quantity in the condensed water. These salts, in presence of grease, at a temperature not exceeding 60° to 70° C., form lime-soap—part of the lime salts being, as has already been shown, rendered insoluble at these temperatures. The lime-soap, under the influence of a higher temperature, partially decomposes into free fat acid and an organic substance which is reducible by further heat, yielding a carbonaceous residue.

This substance is a kind of basic lime-soap which adheres to the boiler surfaces, while the acid, which is usually oleic acid, attacks and dissolves the iron. In the crust the fat acid is recognised by the addition of hydrochloric acid, the separated organic mass being afterwards shaken with ether. The boiler crusts have usually a dark color, partially due to the presence of oxide of iron, partly to separation of carbon from the fat acid partially decomposed. Even if lime and magnesia salts are present in very insignificant proportion, the presence of grease is none the less injurious, as with saponification under great pressure, a very small quantity of lime suffices to occasion the splitting up of a neutral fat into free fat acid and glycerin; with low pressure it is not doubted that the same decomposition occurs, though more gradually.

A sample of very soft water (6° of hardness) depositing very little crust, was submitted to the author of that paper, as a boiler in which it had been used was completely destroyed after three years' work. This water had a milky appearance, and contained 0.212 parts of fat in one litre.

He also quotes the case of the corrosion of a gasometer, the cistern of which had been luted with greasy condensation water. The gasometer would have lasted twenty or thirty years had ordinary water been used, but in the circumstances mentioned, that part of it exposed to the water was corroded through after four years.

The destructive action of the oleic acid on the oil-pumps used in stearin candle manufactories is also alluded to. And the following details are given of an interesting case of boiler corrosion, with accompanying incrustation, and of the means used to overcome the destructive action. The condensed water from two steam engines, respectively of 300 and 100 horse-power, was used to feed a steel boiler of the Cornish design. After only three weeks' firing, water began to leak into the tubes, and shortly after the boiler had to be stopped for examination and repair. A deposit on the upper part of the tubes, from eight to eleven mm. thick, was found. The water had an opalescent appearance, at once removed by ether, which the author recommends as a good qualitative test for the presence of grease in water. The following is the result of analysis of the condensed water, which was obtained at a temperature of 40° to 50°.

	In 10,000 parts.	
Calcium carbonate.........	1.3091	"
Magnesium carbonate.. ...	0.6930	"
Calcium sulphate...........	0.3158	"
Magnesium chloride........	0.0134	"
Sodium chloride............	0.1200	"
Ferric oxide and alumina...	0.0241	"
Silica..........	0.0023	"
Organic matter....	0.4138	"
Total...	2.8915	"

The crust deposited from this water had a dark greyish-brown color and was friable; but when pulverised it was difficult to wet with water. It effervesced strongly with hydrochloric acids, a black fatty mass being left floating on the surface of the acid, which shaken with ether yielded thereto about 5.19 per cent. of a brown oil. The residue insoluble in hydrochloric acid was washed with ether to remove fat, dried at 100°, weighed and ignited. The following shows the full analysis :

Calcium carbonate	51.42	per cent.
Magnesium carbonate	11.30	"
Magnesium hydrate	3.90	"
Calcium sulphate	6.63	"
Ferric oxide	12.75	"
Alumina	0.31	"
Silica	0.34	"
Fat acids	5.19	"
Combustible matter	8.46	"
	100.30	

In order to purify the water, the calcium carbonate and part of the magnesium carbonate, with all the grease, were removed by precipitation and subsequent filtering. The fat particles were removed by being enveloped by the precipitated calcium carbonate, which mechanically retained them on the filter, the reaction being favored by suitable temperature and intimate mixture previous to filtering.

The water then contained in	10,000 parts.
Calcium carbonate	0.1773 "
Magnesium carbonate	0.4135 "
Calcium sulphate	0.2068 "
Magnesium chloride	0.0108 "
Sodium chloride	0.2351 "
Silica	traces.
Ferric oxide and alumina	traces.
Organic matter	0.1512 "
Total	1.1947 parts.

No grease could be detected in the filtered water, which was then used in the same boiler, after being repaired, for three months, when the deposit on the tubes was found to amount to a layer of only the thickness of a sheet of paper and almost wholly consisted of gypsum, and easy to remove. The whole amounted to only five kilometers in weight after three months' steady work. It was a loose greyish-brown mass, the following showing the analysis :

Calcium carbonate	19.30	per cent.
Magnesium carbonate	1.26	"
Magnesium hydrate	45.02	"
Calcium sulphate	15.12	"
Ferric oxide	9.43	"
Silica	2.04	"
Organic matter (insol. in ether)	7.35	"
Fatty matter	traces.	
	99.52	

To purify such water as the above-named for high pressure boilers, a mixture of lime-water and caustic soda solution is recommended, as this not only removes fat acids but also removes the magnesia, which forms with gypsum hard incrustations at high temperatures. (*Dingler Polyt. J.*, ccxv. 115-121, *Chem. Soc. J.*, vol. xiv., sec. 2. p. 132.)

In a letter on the corrosion of boilers, addressed by me in October, 1874, to the Editor of *Engineering* (and published in that paper on October 23, 1874), reference was made to the Report on Corrosion of the Tubing of two of Rowan & Horton's Patent Boilers, by Mr.

Thomas Spencer, an analytical chemist. Starting from the slender basis afforded by the examination of water mains in two cases of internal corrosion of these, where a very pure natural water was conveyed through them, Mr. Spencer argued that the corrosion in these boilers was due to the use of distilled water, which alone was used in them, but which he confounded with pure natural water. In the absence of any well ascertained facts as to boiler corrosion, his opinion was accepted as sufficiently explanatory of the action; but, as is often the case with half-knowledge, that which was true in his investigations, was rendered indistinct by crude conjectures. In consequence of this, in the letter referred to, and generally in all published opinions emanating from engineering sources which I have seen, neither the great difference between genuine distilled water and pure natural waters—viz., the quantity of air and gas which is invariably held by the latter—has been properly weighed or even acknowledged, nor has the only point of similarity between the distilled water from surface condensers known on board steamers and pure fresh water—viz., that there is always some air present in the former—been noticed or allowed for. In the letter referred to, I regret that I was misled into confounding distilled water with Loch Katrine water, having in view merely purity, and not considering the presence of air or gases.

In considering now some examples of boiler corrosion, I shall adopt the arrangement already used in the section on Incrustation, viz :

1. Land boilers using natural fresh waters; and,
2. Marine boilers.

1. From what has been before us in connection with Incrustation, it is plain that it is in those land boilers only which are fed with pure natural waters that we are likely to find Corrosion at work. Where lime salts are present, a crust is formed, and the metal surfaces of the

interior of the boiler are thus kept from contact with the water and any corroding ingredient in it. The special inconveniences of such crust formation we have already considered. Highly chalybeate waters, although not depositing a crust, do not seem to act injuriously. A case is mentioned in Mr. Jas. Napier's paper in *Proc. Phil. Soc. G.*, demonstrating this. There may, however, be some material forming part of the crust, or adhering to it, which suffers decomposition in contact with the heated iron, and, as a consequence, attacks the metal. This is the case with crusts formed with fat or greasy substances, as in the instance already quoted in the paper by Stingl.

We have, in this district, ample opportunity of proving the effect of very pure fresh water upon boilers, because there are few natural waters of greater purity than that from Loch Katrine, with which various manufactories in and around this city are supplied.

The water formerly supplied to Glasgow having been calcareous, it has been found that boilers which used it for some time, have not suffered from corrosion when subsequently fed with Loch Katrine water—the explanation of this being the fact that the thin coating of lime which these boilers had acquired acted as an efficient and permanent protection.

Where, however, owners or managers have been very zealous in removing by mechanical or chemical means every trace of that crust in order to get the full benefit, as they have thought, of the pure water, the result has been different and "the full benefit" has often been of a kind to perplex them. When also new boilers have been started from the first with Loch Katrine water corrosion has been more or less rapid, and considerable trouble and inconvenience have been caused thereby.

These facts find illustration in many manufacturing establishments around. I have been informed, amongst others, of a boiler attached to a mill in Bridgeton where every care was taken to remove all scale before introducing Loch Katrine water, and the millowners were chagrined by finding their boiler quickly suffer from corrosion.

In an engineering work at Port-Dundas (Rowan & Co.'s), one boiler which had wrought upon a supply of the former calcareous water, and was latterly supplied with Loch Katrine without being scaled, continued to work for some years without showing symptoms of distress from corrosion. In the same works, however, a range of new boilers, put down after the introduction of the pure water, suffered so severely as to require constant repairs at tubes, and an entire new set of tubes (of between forty and fifty in each boiler) in a comparatively short time. In another engineering work on the south side of the city (A. & W. Smith & Co.'s), the mains hop boiler was worked for three or four years without suffering corrosion with Loch Katrine water, after having worked previously for seven or eight years with the former

Glasgow water. When a new boiler was substituted for this old one, although the new one was subjected to precisely the same conditions as those its predecessor wrought under for some years without trouble or difficulty, it was found to the consternation of the proprietors that the new boiler was corroding away so fast as to suggest that a third boiler would be required very soon. Until the presence and effect of the lime coating in the former boiler were pointed out, it was impossible for them to understand how one boiler should be able to use Loch Katrine water without damage, while another similarly worked should suffer in so short a time.

In the former of these two examples no condensed water was fed into the boilers, as they were working in connection with high pressure atmospheric engines and other machines; consequently there was no grease or other corrosive agent introduced into them, and thus the corrosion could be traced directly to the water. In the latter one, a part of the condensed steam was collected in the feed cistern, and a considerable quantity of grease thus found its way into the boiler, thus aiding the corrosion somewhat. Steps were at first taken to exclude this grease from the boiler but the corrosion afterwards proceeded—large quantities of oxide of iron being removed from the boiler—until means were adopted to overcome the action.

The following is the result of the analysis of the water made during July, and published by Prof. Mills, who informs me that it represents a fair average of the quality of the Loch Katrine supply :

	In 100,000 parts.
Total solid impurity	3.16
Organic Carbon	0.110
Organic Nitrogen	0.033
Ammonia	—
Nitrogen as nitrates and nitrites	—
Total combined Nitrogen	0.033
Chlorine	0.70
Hardness	0.48

The report also bears that the water was pale brown in color and contained traces of fibrous matter and muddy particles, and that the general condition was very satisfactory.

Nothing contained in the water as impurity can account for its destructive action; but the fact that it contains seven to eight cubic inches of gas (of which about three cubic inches are oxygen) to the gallon in solution, coupled with the investigations already quoted in this paper, as to the effect of distilled water without gas and of water containing gas, makes all plain. The corrosion is due to the action of the carbonic acid and oxygen held by the water, and the action is all the more rapid, from the absence from the water of any mineral matter with which the gases can combine. In both of these engineering works an artificial coating of lime was formed in the interior of the boilers, by feeding regularly into them each morning for some time a whitewash of Irish lime and water. This expedient was quite successful in checking the corrosive action, and as the lime soon hardened, under the influence of the heat, no trouble was experienced in preserving the coating. Pieces of limestone were also placed in the feed tank or cistern, but it is doubtful if they produced much effect. The carrying out of the application of lime in this way, was due to the ingenuity of Mr. T. R. Horton. Where, however, it is possible to mix with Loch Katrine or other pure water, a proportion of a calcareous natural water for a time, the scale formed thus in working will probably be of a more enduring nature. I strongly recommend this plan to those using Loch Katrine water, who have access to former sources of supply.

2. MARINE BOILERS. We are introduced to a variety of corrosive actions in considering marine boilers, according as we have to deal with boilers working with nothing but fresh water or those which use a proportion of sea water. It is necessary, however, clearly to distinguish these two classes.

The only marine boilers as yet using exclusively fresh water in regular working with which I am acquainted are those of Rowan & Horton's, mentioned in the letter to *Engineering*, to which I have referred, and elsewhere, and those working on Perkins' plan. Some of the ordinary boilers used in steamers with what are called compound engines, have been occasionally wrought entirely with fresh water, but in every such case recorded, that manner of working was abandoned after a very short trial, in consequence of the rapid corrosion which was discovered to be going on. Boilers in vessels whose voyages are always made in sea water, are constantly liable to receive a small quantity of salt water by leakage through surface condenser joints, or some other connections, so that even where it is or has been the intention to use fresh water only, it is not possible without analysis to determine if that has been done. The first of the examples quoted above have, however, this element of uncertainty removed from their case in consequence of their steamers running in fresh water, except for a very small part of their voyage. In their case corrosion from fat acids and from galvanic action, of what may be called an intermittent kind, was experienced and successfully counteracted. These actions, and the respective remedies which were adopted, I have mentioned in the published letter referred to, and I quote them here because they show what are the corrosive forces to which marine boilers, working exclusively with fresh water, may be subjected. Lime was present in small quantity in the river water used to fill up the boilers at starting and to make up waste in working, so that the decomposition of fats already described could take place. When the grease was removed as much as possible by filtering the feed water, and the presence of any free acid neutralised by zinc the corrosion ceased. The galvanic action was also arrested by means of the filter, because in general this action is caused by local contact with particles of metal carried into the boiler, and not, as has been erroneously supposed, by means of the surface condenser and the boiler forming together the two elements of a huge battery, the steam and water being the exciting medium.

Of Perkins' boilers worked in steamers, we have no published accounts with which I am acquainted, so that we cannot say whether they have suffered from corrosion in the course of the exigencies of practical voyage making. It is, I know, the aim of Mr. Perkins to exclude if possible all sea water, and all oily matter from his boilers, and if successful in doing this, and working only with fresh water, the corrosion will not be great. Still there will be some, as the gases of the natural fresh water with which the boilers are filled at starting will oxidise their proportion of iron, and in the feed water, which, as condensed steam has been returned from engines through the surface condenser and discharged by the air pump into the hot well, there is of necessity (probably not much), yet some air present, as the condensation takes place in contact with air;

and this air will also do its own share in corroding fresh portions of the clean surface of the boilers. It is probable that if these boilers are introduced into merchant steamers and become subject to the invariable emergencies of regular trading by which leakages, deficient supply, and contamination of feed water are experienced, and foreign substances find their way into the boilers, the evils of corrosion may be known to a greater extent than that to which they reach, where it is possible to observe all the precautions of the inventor of that system.

Generating steam from fresh water alone is undoubtedly the proper, as it is sure on this account to be ultimately the general, mode of operation with steam boilers, but for ordinary sea-going purposes, appliances must not be too delicate, but require to possess the power to endure abnormal and adverse conditions.

The case of a coasting steamer using in her boilers natural fresh water from two sources (one at each end of her voyage) whose boilers were destroyed by corrosion with great rapidity was made known by Mr. James Gilchrist, in a paper read before the graduate section of the Inst. of Engineers in Scotland, and published in February of this year in a periodical called *Marine Engineering News.* Analysis of one of these waters (the other having been Loch Katrine), and of the deposit found in the boilers are given in the paper with the opinions of two professional chemists, who ascribed the corrosive action to the injudicious use of a large quantity of tallow in engines and boilers. There is no doubt that the decomposition of the tallow was in itself sufficient to cause serious damage to the boilers in presence of fresh water containing a small quantity of lime; but the action in this case was modified by a fact not noticed by the chemists—viz., that during the voyage of the steamer all deficiency in feed water was made up from the sea. The boiler deposit consequently contains

9.11 % of magnesia, and 12 % of common salt, as well as 8.86 % of oil and organic matter; and it is to the presence and decomposition of chloride of magnesium to which the presence of magnesia in the deposit bears witness, as well as to the carbonic acid of the original boiler supply, that a great part, and probably the rapidity of the corrosive action, is, I believe, to be attributed.

This leads to the consideration of marine boilers using partly fresh and partly salt water, by far the most extensive class at present, and that which has suffered most from corrosive action.

A very intelligent account of the state of matters in this class of boilers is given by Mr. Milln, in a paper read before the Cleveland Iron Trade Foremen's Association, Nov., 1875, and published widely in the engineering periodicals. This author describes graphically the introduction of the surface condenser into marine engine practice, with which is coincident the commencement of all real trouble from corrosion, and he then describes the course of events with two distinct sets of marine boilers. In the first of these we have a good example of boilers which had been worked at comparatively low pressure, viz., twenty-five pounds per square inch and fed for four years with sea water—working during that time in connection with an ordinary injection condenser attached to engines which indicated 900 horse power. As the voyage was not of long duration and time was given for regular "scaling" of the boiler surfaces (i.e. removing the scale from them) at the close of every voyage, no damage was done by incrustation and no inconvenience beyond the cost of fuel consumed was experienced. The injection condenser was then replaced by a surface condenser, some of the old incrustation being left adhering to the boiler surfaces, and the boilers were worked for some time thereafter with fresh water, the deficiency in feed supply being made up from the sea. The crust was soon removed and the boilers corroded, showing pits and blotches and all the usual symptoms.

The other instance quoted by Mr. Milln is that of a new set of boilers working at sixty-five pounds pressure in connection with compound engines of 1700 horse power and surface condenser, evidently an excellent example of average modern steamship machinery. These boilers were worked from the first with fresh water, the waste being supplied by distilled water, yet the density of the water increased daily and corrosion proceeded at the same time most energetically. After one voyage the boilers were filled at starting with sea water, but no more sea water was added during the voyage except the small quantity necessary for surplus feed supply. Under these fresh circumstances corrosion still proceeded, though it was thought more slowly, and was only finally stopped by what is called "changing the water," i.e. blowing off a quantity regularly and replacing it with sea water, thus introducing fresh quantities of sea water into the boilers during the voyage.

This author then alludes to the many theories explanatory of corrosive action which have been started, but only to reject them all and adopt the popular error, that corrosion is due to a change supposed to be wrought upon the water itself by distillation or re-distillation, which according to some, confers upon it the properties of a powerful solvent of metals, and according to others, although they do not like to state it thus plainly, this distillation decomposes the water and dissociates its oxygen, which forthwith attacks the iron of the boilers, or as Mr. Milln puts it: "the constituent elements of water when frequently redistilled undergo such a change as to greatly intensify its action on or affinity for iron," One engineering journal indeed very confidently affirms that it is "a fact but too familiar to engineers that the continuous boiling of distilled water in an iron vessel causes the destruction of that vessel," but has to admit that the circumstance that that water also passes over a very great surface of brass or copper, (of the destruction of which, however, not a word is said,) complicates the aspect of the phenomena.

It must, however, be confessed by engineers, that of the data or investigations by which so apparently wild a theory has been established as a fact they are as yet profoundly ignorant, and as Mr. Milln observes "it is with regard to the nature of this change that we so much want information!" There is this solitary fact known and harped upon, viz.: that dry steam in contact for a period of time with iron or carbon in a tolerably fine state of division and at a red heat is decomposed hydrogen gas escaping, while the oxygen combines with the iron or carbon. But this has never been attempted with water nor can be done with steam below red heat. What is known of the action of distilled water proves, indeed, the clean contrary to this theory, and in illustration of "what is known," I refer to those investigations which I have already quoted. They prove that it is the presence of air or gases which makes the difference in the action of various pure waters, and even in that of the various salts dissolved in impure waters, and that when water is distilled free from air, its corroding power is lost. Thus the remedy for corrosion proposed by some engineers to-day—viz., that the condensed steam should be aerated, proves to be a foolish suggestion, for this would but *increase* the power of that water to corrode the iron of the boilers.

I shall be within the strict truth when I say that it is hasty to conclude, from examples of boiler corrosion, that distilled water has to do with the corrosion, for the fact is that there is no case known in which the proper effects due to the employment of distilled water alone, and free from gases, upon the metal of boilers, could have been observed. The boilers of Rowan & Horton, and of Perkins, present the nearest approach to the conditions requisite for such information, but not all the necessary conditions are found even in these instances. The examples just quoted from Mr. Milln's paper are of the kind with which engineers are more generally familiar, and they do not give such data as would lead to the conclusions about distilled water. The opinion is therefore due to a hasty conclusion, drawn from the coincident occurrence of corrosion with the introduction of surface condensers.

In the first example, genuine distilled water was never present. The boilers were filled up with fresh water at starting with the surface condensers, but not only was waste and deficiency of feed made up from the sea during the voyages, but there was also the saline crust adhering to the boilers to be dissolved or partially dissolved by the fresh water. Contrary to the opinion of Mr. Milln and others, I maintain that just because analysis shows that such crust contains chloride of sodium (in appreciable quantity when formed at such a pressure as that of the boiler mentioned—viz., 25 lbs. per square inch), if not also other soluble ingredients, a certain part of the crust must have been—and in such cases always is—dissolved; and thus the crust is partially disintegrated, and the insoluble magnesia and sulphate of lime fall in flakes to the bottom of the boiler. The fact that the water did not long remain fresh does not in any way interfere with this opinion, for it is a fact well known that salts dissolve more readily in a solution of other salts than in fresh water. Hence the scale would come off even more rapid when a small quantity of sea water was used.

The second example started with boilers filled with natural fresh water, which itself has (as we have seen), if pure, power to corrode by its gases in solution; but although distilled and not sea water in this case was used for surplus feed supply, the salinometer test showed plainly that pure distilled water was never present, and that either sea water was getting in through a leaky condenser, or that fatty and other matters were accumulating in the boiler, the color and taste of the water being decided indications that such (and probably *both* of these) results were happening. After the first voyage which gave such results, sea water was regularly used in greater or less proportion.

Thus we must search for the corroding agents apart from the distilled water. The analyses by Dr. Wallace and others, of boiler crusts, and the researches of Wagner and Fischer quoted herein, reveal one very important one—viz., the chlorine or hydrochloric acid set free by decomposition of the chloride of magnesium in the sea water. This decomposition may take place under the influence of high temperature alone, when magnesium hydrate is deposited, while the iron is attacked by the hydrochloric acid, first cloride and subsequently oxide being formed. As the combined influences of temperature and carbonate of lime are present, it is probable that the sulphate of magnesia is also decomposed, and that some oxychloride of magnesia is also formed, but this has not yet been demonstrated by analysis of deposits, though it is the opinion of Dr. Mills and others that part of the magnesia reported in ordinary analysis of boiler deposit from sea water exists in that form. Dr. Fischer also demonstrates that this mutual decomposition of magnesium sulphate with calcium carbonate is a fact, and that the liberation of carbonic acid also necessarily takes place.

The researches of J. Y. Buchanan "on the power of sea water to absorb carbonic acid," to which I have already referred, have shown us that sea water, on account of the sulphates which it holds in solution, absorbs a large amount of that gas, which it readily gives up on the sulphates being decomposed or separated from the water. Such decomposition and precipitation of sulphates occur in marine boilers, besides there being, now since the surface condenser era, repeated boiling of the water, which of itself in time liberates nearly all the carbonic acid. We have in these two agents, viz—the hydrochloric acid of the decomposed chlorides and the carbonic acid, combined with high temperature and pressure, quite enough to account for most of the corrosion which occurs.

The researches of Stingl, which I have quoted, show the power for evil which greasy matters wield, and this specially I believe where the water is comparatively fresh, though not there alone. And where grease is allowed to reach the boilers it can also carry along with it particles of other metals, which, in spite of the incredulity of some engineers, have been found to do mischief, and are capable of doing, if possible, more in presence of salt water than with fresh, unless it be acidulated. It is not supposed that they can do *all* the mischief, or even any in places to which they cannot reach; it is sufficient that they are capable of doing some, and there are specimens extant (among the specimens collected by the Admiralty committee on boilers, for instance) of corrosion and abrasion of brass tubes and other parts of engines, which show that this is a real and not a fancied danger.

The simple explanation of the fact that all such corroding agents have done damage principally since the introduction of the surface condenser, is that the surface condenser, by separating the condensed steam from the sea water used to condense it, and by returning so much fresh water to the boilers, has reduced the proportion of sea water used in them below that point at which it is possible to form a protecting scale or crust by the saturation of a considerable quantity of sea-water. It also, as I have said, provides for the complete liberation, by repeated boiling, of the carbonic acid held by the sea-water.

That sea-water alone at the boiling point corrodes iron is proved by one of Wagner's experiments, in which the percentage of loss from a piece of iron plate which was kept in contact with boiling sea water and air for six weeks, steadily increased from 0.43% after one week to 1.24% after six weeks. And proof that in marine boilers a small proportion of sea water is capable of doing mischief while a large quantity is not, is found readily in the fact that engineers have repeatedly *arrested corrosive action* by simply increasing the quantity of sea-water in the boilers, but without altering any of the other conditions of working. It is always in boilers that are "worked fresh" (*i.e.*, with the minimum of sea-water) that corrosion proceeds most rapidly, and I know of one steamer (the S.S. Vespasian) where by continually working fresh, a new set of boiler tubes was required in little more than twelve months after starting, while after that time, in the same boilers, the use of a large proportion of sea-water was enough without further change in working to preserve the boilers from rapid corrosion. As soon as the smallest quantity of scale begins to form, destructive action is arrested. This is true of all the various kinds of destructive action, and explains how under the old regime none of these were known. It also shows how fallacious must be any conclusions drawn from comparisions of results with old boilers in any attempt to argue from them to results in modern ones, as though both were obtained under like conditions. Another proof of the existence of such decompositions as I have described is found in the fact that the water of boilers in which corrosion is going on becomes alkaline. This shows an accumulation in solution of the effect of the alkaline ingredients of the sea-water, by decomposition and the neutralisation of the acid ingredients, and it is for this reason that some have been disappointed by testing the water, who had concluded that if corrosion was due to the presence of acid substances then the water must be acid.

The pitting and blotching effects produced on the metal of the boilers prove on examination to be not so mysterious as our first apprehensions rendered them. The same results follow the use of corroding liquids in any metal vessels when exposed to air and to light. Even basins made of platinum, which is harder and closer in texture than any other metal, I am informed are found by chemists to wear in a similar way by having certain liquids boiled in them, and thus the effects are apparently due to non-homogeneity of the metals as well as to purity in some cases. Heat in most instances has a considerable share in directing the action which is usually found to have been more intense in the hotter regions.

Before adverting to a remedy for this action, I may say that in the boilers of the S.S. Propontis, analyses of crusts from which are given previously, the various results of corrosion were experienced. Increase of density in the water observed when nominally working with fresh water alone, proves from the analysis of the deposite then taken from the boilers, and from an estimation of the total solids in the water at the close of that voyage (made by Mr. Tookey, and found to amount to 3272.5 grains in the gallon), to have been due to leakage of sea-water into the boilers by means of connections with a small boiler used for supplying steam to a cylinder steamjacket. Milkiness and acrid taste in the water were no doubt due to the presence of fatty substances in solution, as a large quantity of grease was collected on the filter through which all the feed water passed. It is probable that these two causes will be found to account in nearly all cases for the increase of density often observed in similar circumstances of working.

It now remains to suggest a remedy. Much has been said in favor of the use of zinc in boilers, but zinc will not do where any proportion of sea-water is used, because it is very rapidly decomposed by the salts in sea-water, and chloride of zinc merely adds to the impurities and evils of the case. It has been, and may be, used successfully in fresh water, where there is free acid to be neutralized, but there its usefulness stops as far as corrosion is concerned.

Filtering the feed water is a most excellent precaution, and should undoubtedly be universally adopted in order to prevent, as far as possible, the entrance of foreign substances into the boilers.

To prevent the corrosive action in them of matters in solution, which no filter can arrest, I believe no better remedy can be found than the forming on the interior surfaces an artificial coating composed of calcium sulphate and magnesium hydrate in proportions varying according to the pressure carried in the boiler. This can be readily fed in, in the form of a thin whitewash with fresh water, and should be applied to all boilers on the very first occasions of getting up steam in them. Otherwise corrosive actions may commence, and unfit the surfaces for the adherence of such a protecting crust. A protecting crust has repeatedly been formed in boilers by using salt water; and in one of Mr. Milln's examples he was able to keep this of proper thinness by regularly blowing off about 1.9th of the water evaporated. Yet this is, as he admits, a very troublesome, and not a safe method of working, and yet to keep such a scale on, it must be carefully carried out without intermission, because as soon as the boilers are allowed to "work fresh" that scale dissolves off. By making an artificial scale with fresh water, as suggested, its thickness is quite under control, and when once hardened by heat, fresh water will not dissolve it, and thus steam can be generated in the best way. Even if a small quantity of sea-water should leak in it is not likely that the coating would be injured.

Apart from such a plan there seems to be no hope of escaping corrosion and advancing at the same time in engineering practice, until it is possible to have copper boilers. And yet, even then, as the recent experiments of Carnelley on "The action of water and of various saline solutions on copper," seem to show, we should still have to combat the same difficulties.

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